Brain-Computer Interface (BCI)

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This tutorial shows HOW-TO find and extract proper signal features from EEG data to separate epochs of EEG into distinct classes. The outcome is a classifier which can be used in real-time Brain-Computer-Interface experiments.

What is Brain-Computer-Interface?

An Electroencephalogram based Brain-Computer-Interface (BCI) provides a new communication channel between the human brain and a computer. Patients who suffer from severe motor impairments (late stage of Amyothrophic Lateral Sclerosis (ALS), severe cerebral palsy, head trauma and spinal injuries) may use such a BCI system as an alternative form of communication by mental activity.

Physiological background

It is a well known phenomenon that EEG rhythmic activities, observed over motor and related areas of the brain, disappear about 1 second prior to a movement onset. Hence one can predict from the spatio-temporal EEG pattern that, for example, a hand movement will be performed. It has also been shown by various groups of researchers that this so-called desynchronized EEG is also observed for an imagination of a hand movement.
The activation of hand area neurons either by the preparation for a real hand movement or by imagination of a hand movement is accompanied by a circumscribed ERD over the hand area. Depending on the type of motor imagery different EEG patterns can be obtained. Hence, one finds also a circumscribed ERD over the foot area in foot movement and foot imagination experiments.

Experimental paradigm and recording setup for the BCI data acquisition

Experimental paradigm

The data set used for classification was acquired during a brain-computer interface experiment with feedback. The session was divided into 4 experimental runs of 40 trials with randomized directions of the cues (20 down and 20 right) and lasted about 1 hour (including electrode application, breaks between runs and experimental preparation). The subject sat in a comfortable armchair 1.5 meters in front of a computer-monitor and was instructed not to move, keep both arms and hands relaxed and to maintain the fixation at the center of the monitor throughout the experiment.

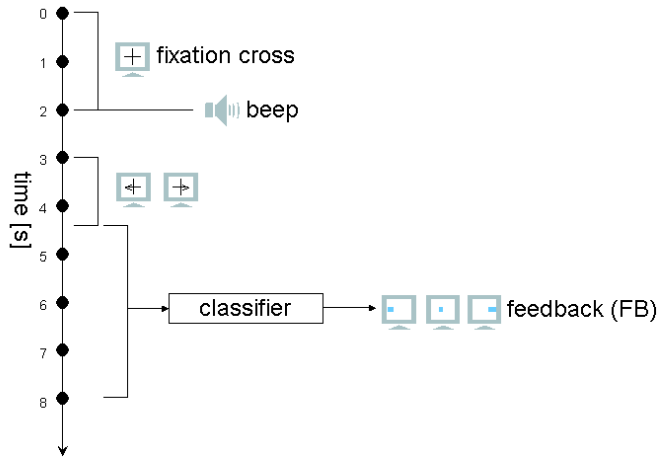


Figure 1: Timing of one trial of the experiment with feedback.

The experimental paradigm started with the display of a fixation cross that was shown in the center of a monitor. After two seconds a warning stimulus was given in form of a "beep". From second 3 until 4.25 an arrow (cue stimulus), pointing down or to the right was shown on the monitor. The subject was instructed to imagine a foot or right hand movement depending on the direction of the arrow. Between second 4.25 and 8, the EEG was classified on-line and the classification result was translated into a feedback stimulus in form of a horizontal bar that appeared in the center of the monitor. If the person imagined a right movement the bar, varying in length, extended to the right and vice versa (correct classification assumed). The subject's task was to extend the bar toward the bottom or right boundary of the monitor as indicated by the arrow cue. One trial lasted 8 seconds and the time between two trials was randomized in a range of 0.5 to 2.5 seconds to avoid adaptation (see figure 1 for the timing of the paradigm).

EEG recording

Two bipolar recordings overlaying the left and central sensorimotor area were placed on the subject's head as indicated in figure 2. The ground electrode was attached to the forehead.

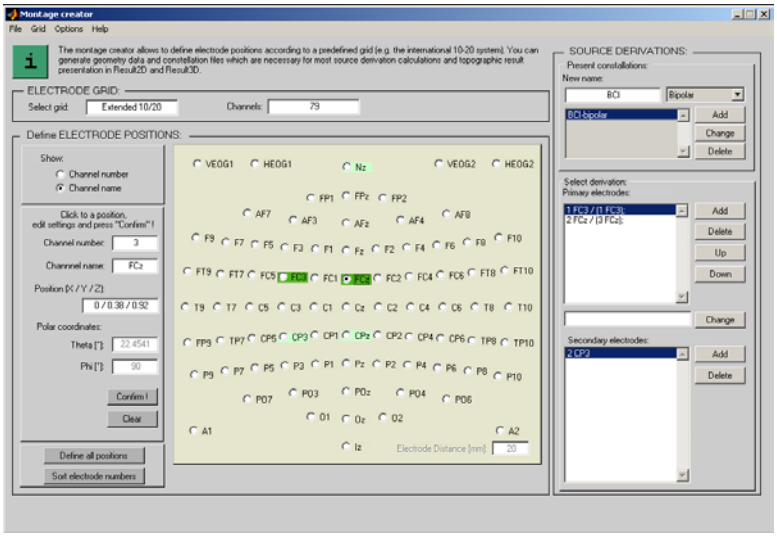


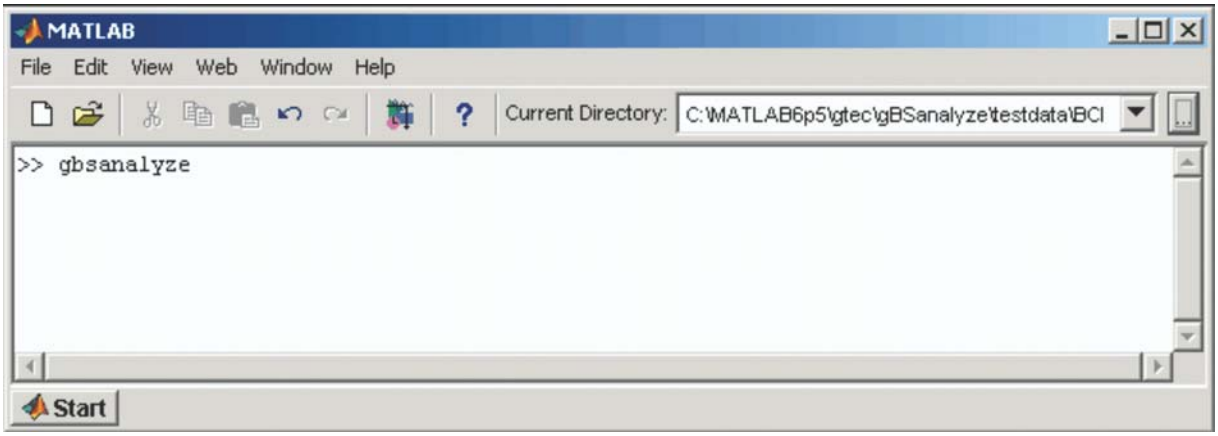
Figure 2: Montage of the 2 bipolar channels. Subject's nose points to the top of the page and the grid is viewed from above. Bipolar EEG electrodes (marked with dark green and light green) and the ground electrode (light green) are defined for further processing. The basis for the electrode positions is the extended international 10/20 system.

The amplified EEG was band pass filtered by an analog filter between 0.5 and 30 Hz and sampled at 128 Hz. The resolution was 12 bits. A notch filter was used to suppress the 50 Hz power line interference.

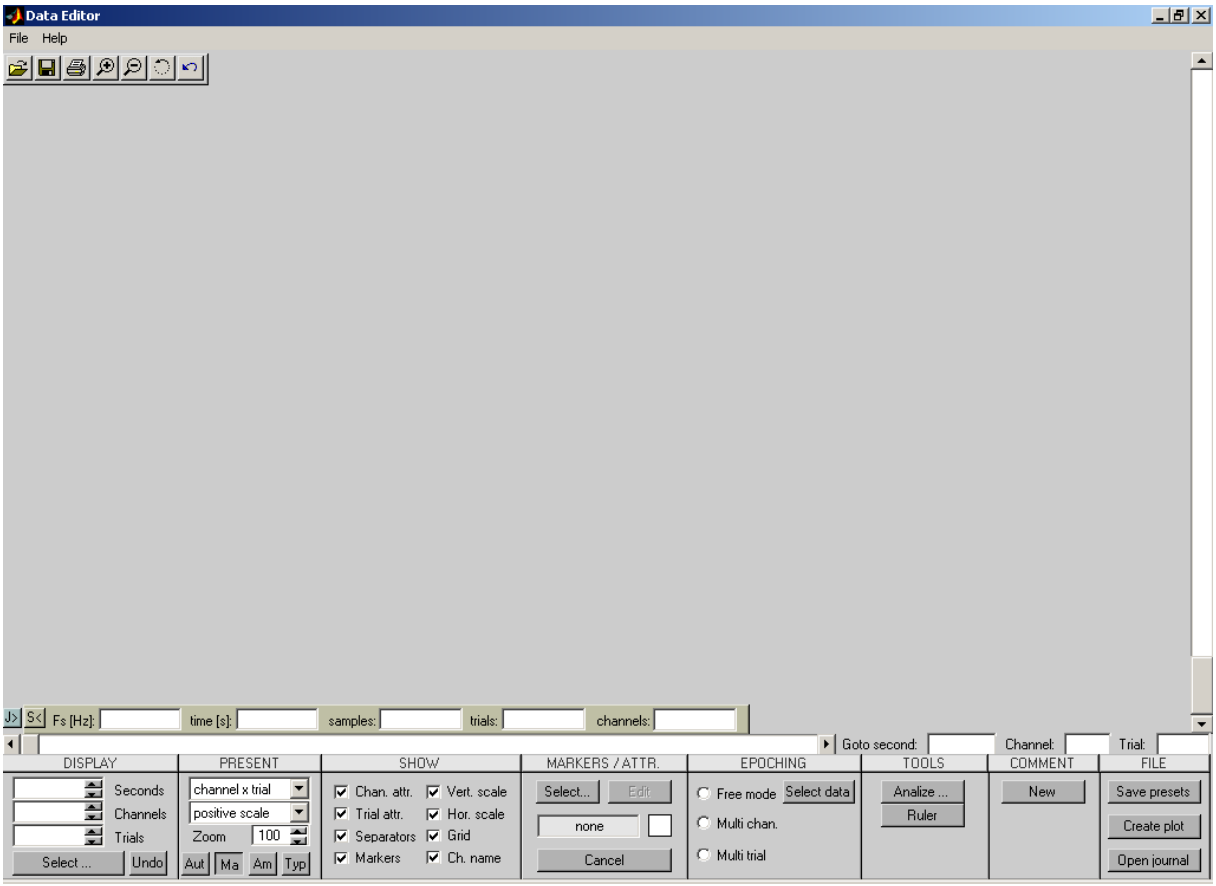
1. Data Inspection

Running g.BSanalyze

1. After starting MATLAB set the current directory to `"MATLAB directory\gtec\gBSanalyze\testdata\bci" and start "gBSanalyze"` in the MATLAB command line.



2. *g.BSanalyze* starts with a blank data window



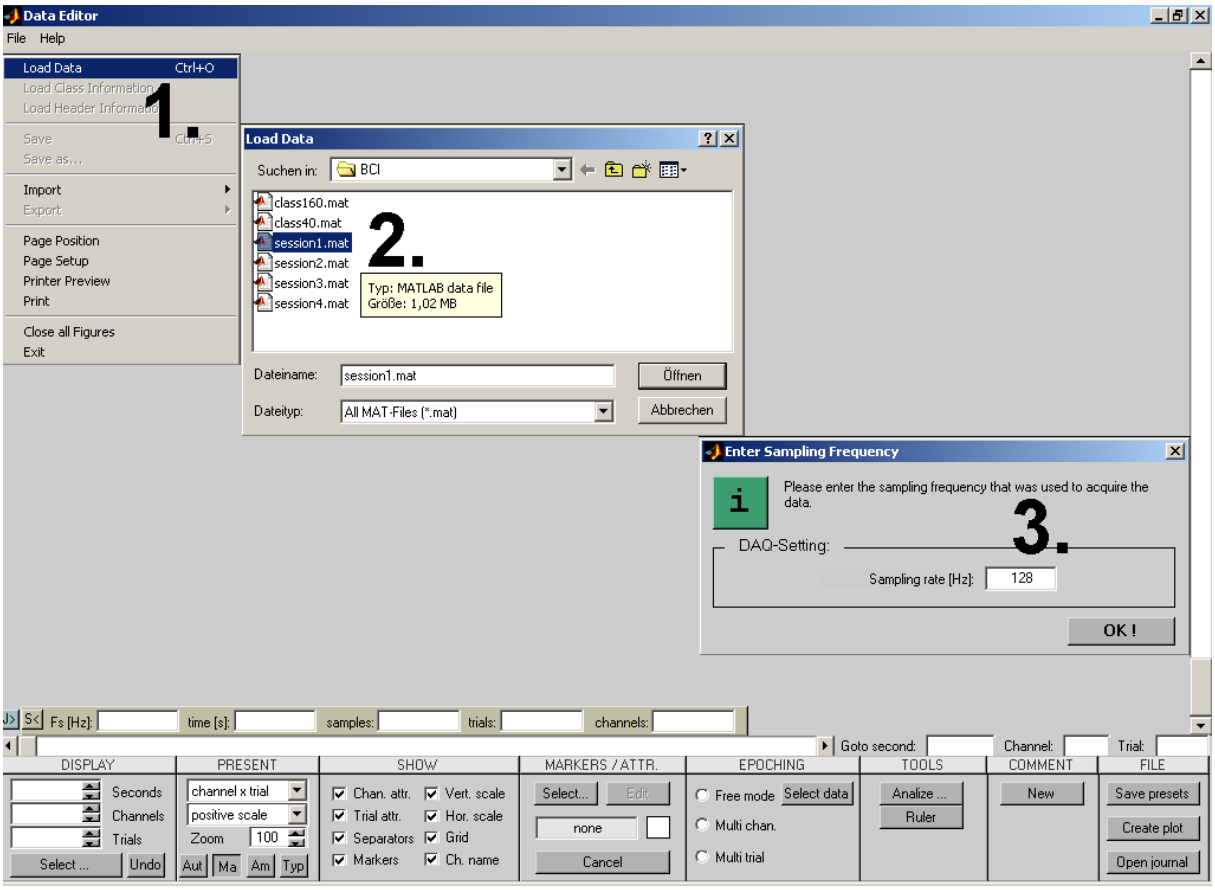
Loading and Viewing Data

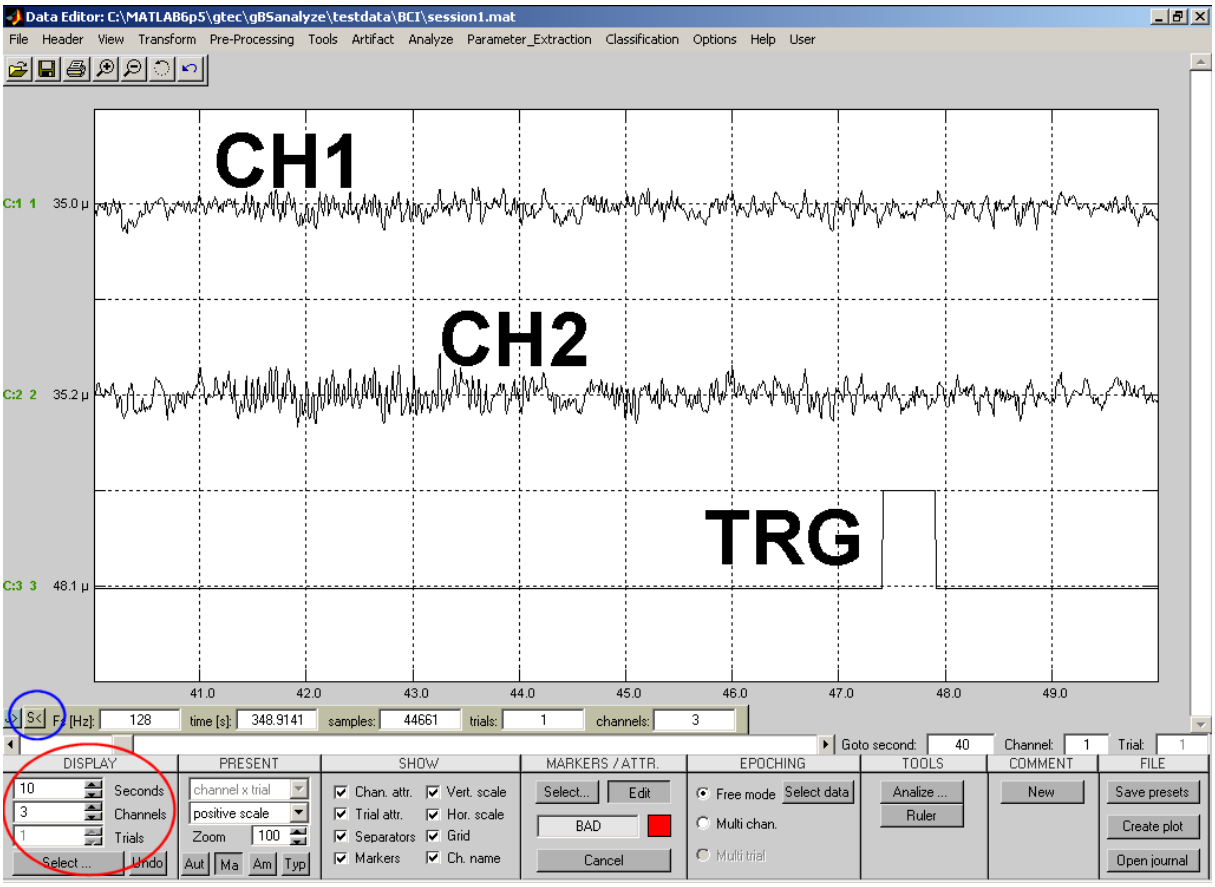
1. Select **Load Data** in the **File** menu

2. Open the data-set by selecting session1.mat from the directory
   `"Your MATLAB directory\gtec\gBSanalyze\testdata\bci"`

3. Enter a sampling frequency of `128 Hz` in the **Enter Sampling Frequency** window

4. Press **OK** and the data are displayed



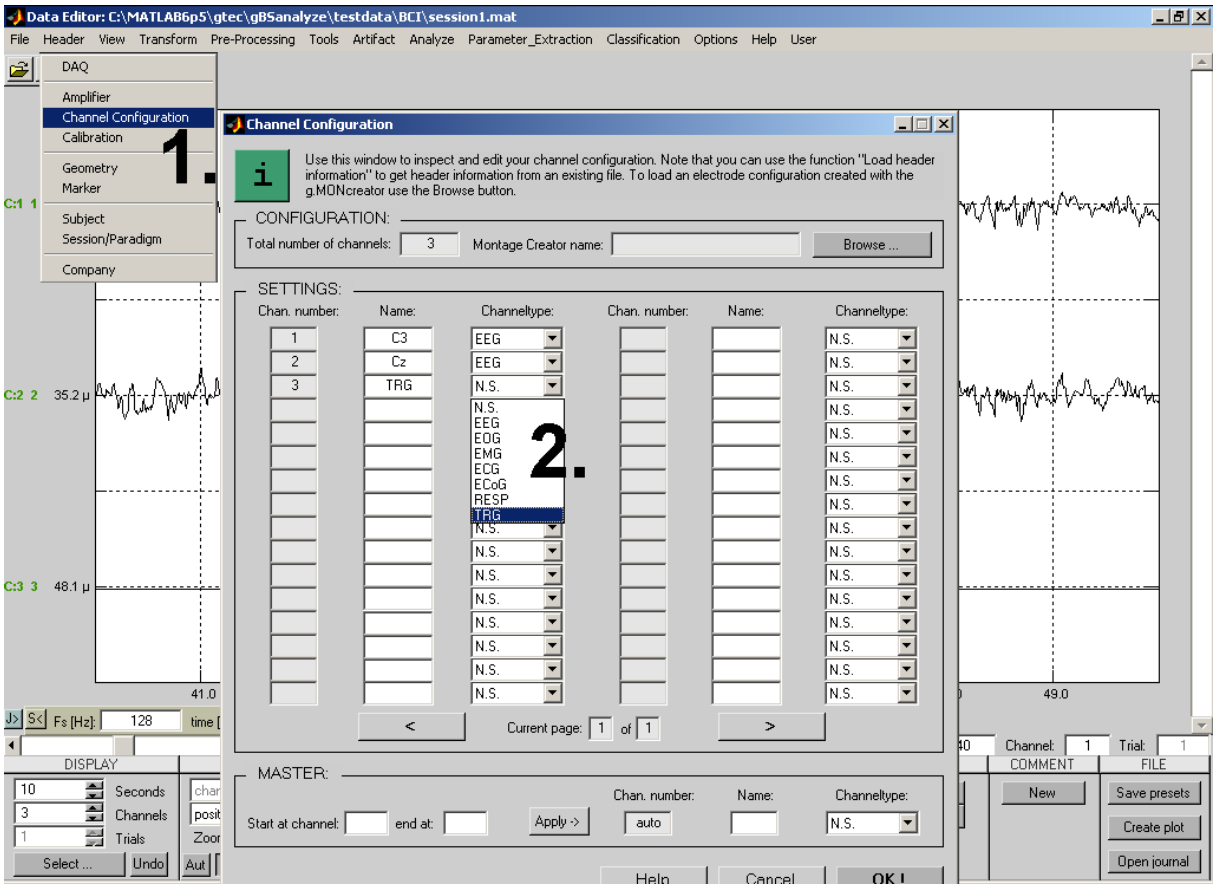


In the display section you can set the number of **Seconds/Channels/Trials** that should be displayed on the screen. Select **10 Seconds** for the number of seconds on the screen and **Goto second 40**. Press on button **S>** for the status information. In this case the status information gives you a sampling frequency of 128 Hz, the total recording time of about 348.9141 seconds with 44661 data samples. The current data set has 1 trial and 3 channels (**CH1**, **CH2** and the trigger **TRG**).

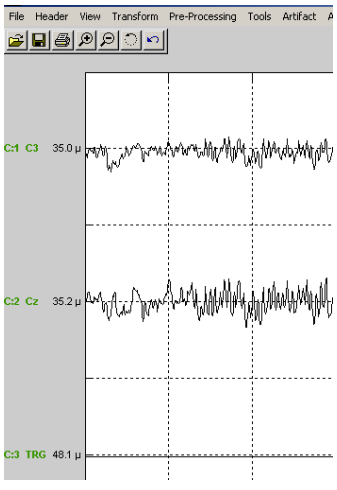
Channel configuration

1. Select **Channel Configuration** in the **Header** menu

2. Assign **Name** C3 to **Chan. number** 1 and choose **Channeltype** EEG
   Assign **Name** Cz to **Chan. number** 2 and choose **Channeltype** EEG
   Assign **Name** TRG to **Chan. number** 3 and choose **Channeltype** TRG



3. Pressing **OK** yields

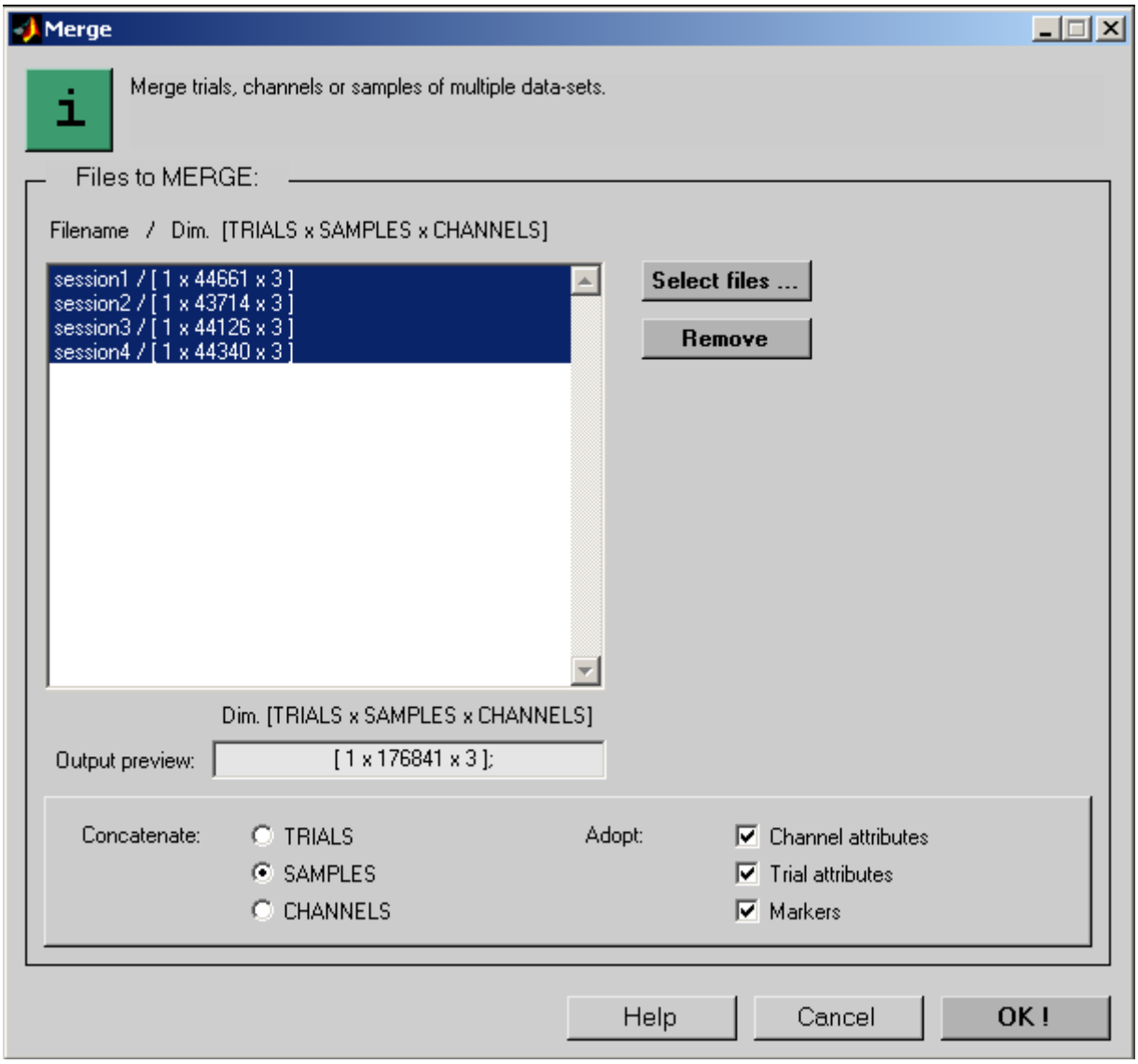


2. Merge Data

A total of 4 so called runs were recorded and stored to disk under filenames `session1.mat, session2.mat, session3.mat and session4.mat`. Merging the 4 data sets together yields to 160 (80 left hand and 80 foot) movement imaginations. For the further analysis of the data a concatenation of all runs is necessary.

Perform the following steps:

1. Select **Merge** in the menu **Transform**
2. Press **Select files …** and choose `session2.mat`



3. Enter a sampling frequency of 128 Hz in the **Enter Sampling Frequency** window
4. Repeat Steps 3 and Step 4 also for `session3.mat` and `session4.mat`
5. Select **Concatenate SAMPLES**. **Output preview** shows the expected result of the merging process. Press the button **OK**.

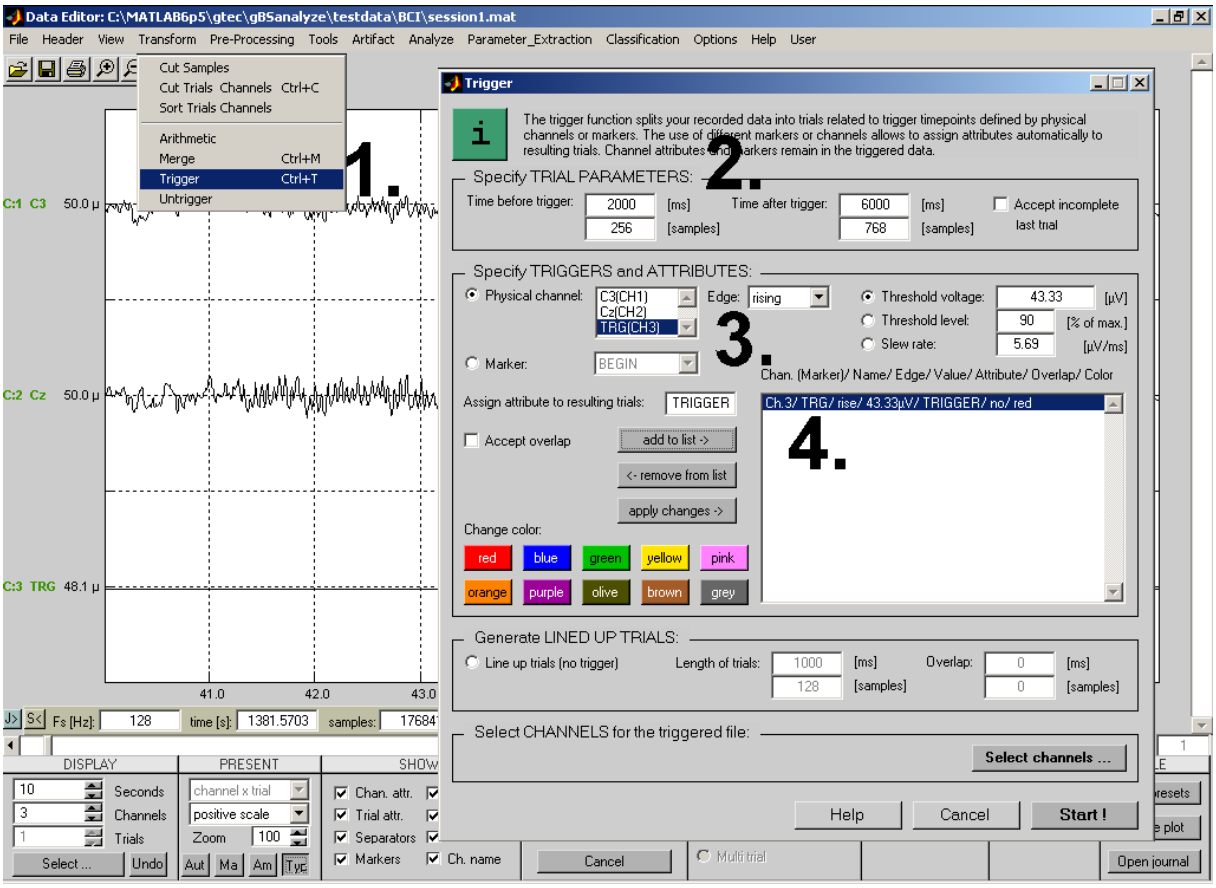
The new data-set consists now of 3 channels, 1 trial and about 4 times more samples as a single data-set (176841 samples).

See **Status** under the **View** menu.

3. Trigger Data

For many calculations performed with biosignal data an epoching or triggering of data-sets is necessary. Therefore, a specific time marker or trigger channel with special events is required. The current data set has 160 TTL-trigger impulses on channel 3 which can be used to split the data into trials of equal length.

1. Select **Trigger** in the **Transform** menu
2. Define the **Time before trigger** as `2000` ms and **Time after trigger** as `6000` ms
3. Select channel 3 in **Physical channel** as trigger channel and set the **Threshold level** to 90 % of maximum
4. Select e.g. the name `TRIGGER` in **Assign attribute to resulting trials** and press button **add to list ->**
5. Press **Start!** to perform the triggering



The status bar in the editor windows shows the result: the number of trials is 160 and one trial has a length of 1024 samples.

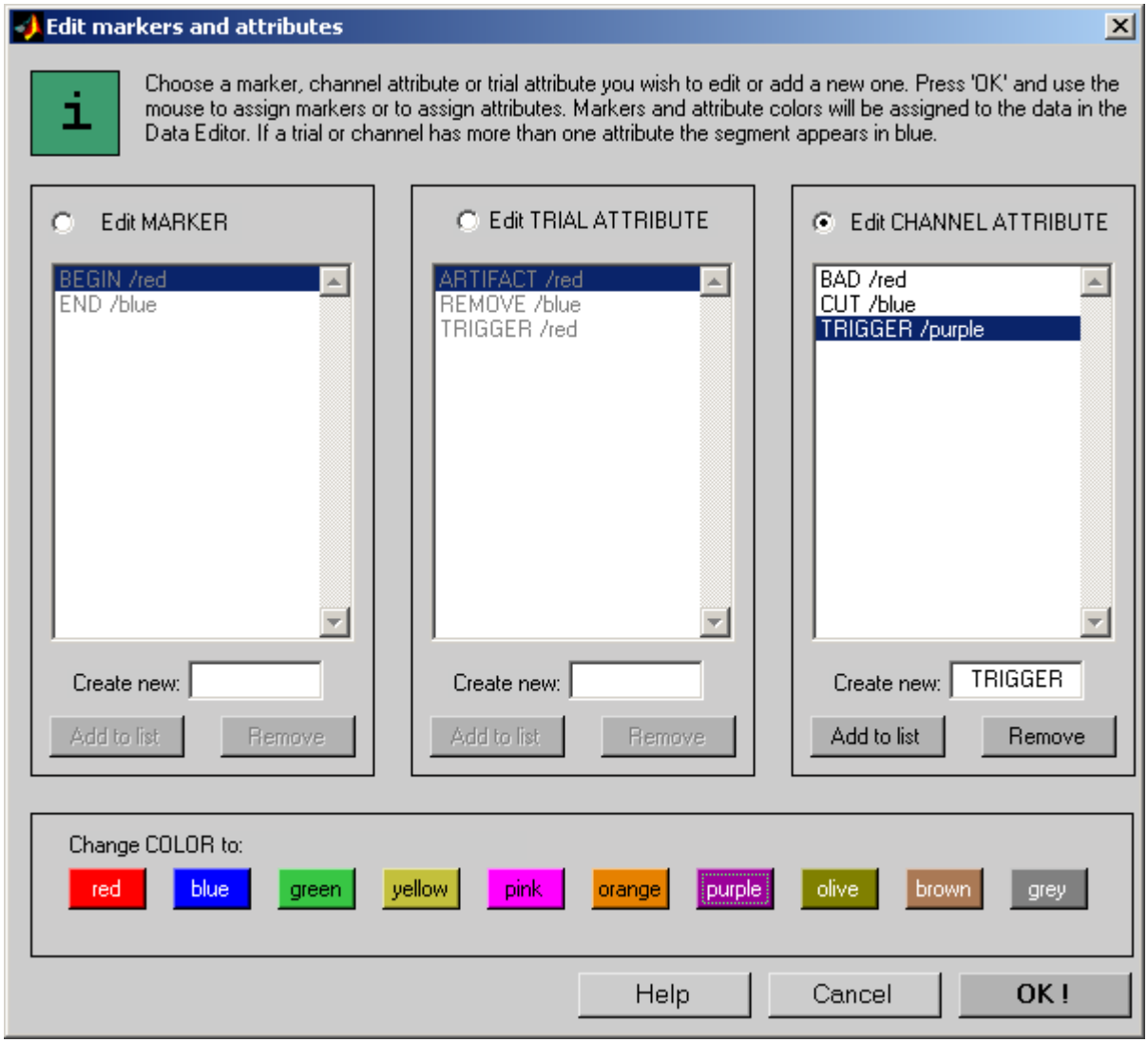
4. Assign Attributes

g.BSanalyze allows to assign channel attributes and trial attributes which are used for further calculations to include or exclude specific trials or channels. Trials with EOG, EMG or overflow artifacts can be marked with the trial attribute ARTIFACT to be excluded from further processing or with the attribute REMOVE to be deleted. Also channels, which are not relevant for further processing such as the trigger signal after triggering or channels with noise, can be marked with BAD to be excluded. On the other hand it is also possible to assign a trial attribute like RIGHT to indicate a right hand movement and to include only trials with the RIGHT attribute in further calculations.

To assign attributes perform the following steps:

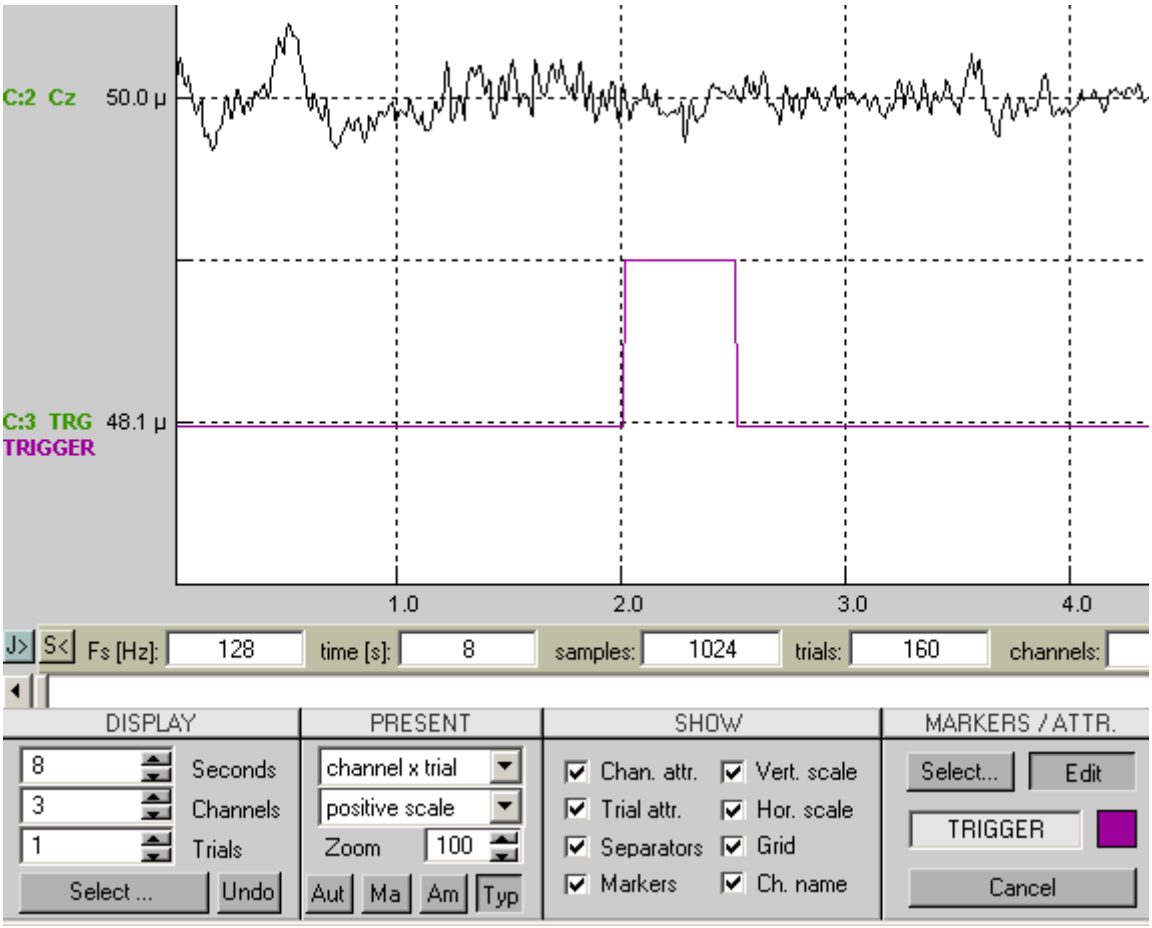
1. Press **Select** in section **MARKERS/ATTR.**

2. Click on **Edit CHANNEL ATTRIBUTE** and enter TRIGGER under **Create new**. Press the button **Add to list**. Click on **button purple** to assign a new color



3. Close the window with **OK !**

Assign the attribute TRIGGER to channel 3 by clicking onto the line that represents channel 3. The attribute TRIGGER is indicated at the left border of the window.



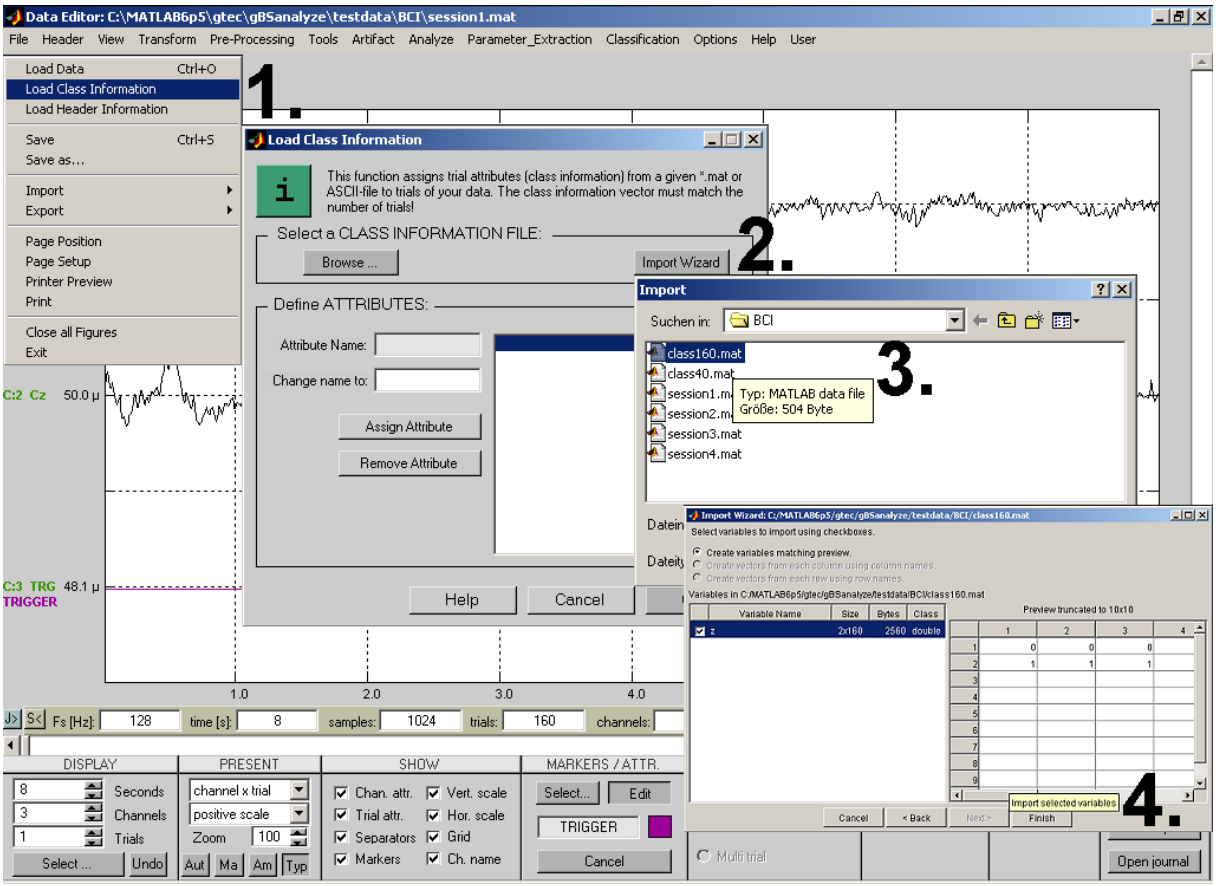
5. Load Class Information

The **Load Class Information** window is used to assign trial attributes to the data from a given `*.mat`, or ASCII-file. The loaded class information vector must match the number of trials. Assume that you have loaded a data file with 3 trials into *g.BSanalyze*. An appropriate class information vector would be 0 1 0. Load class information would assign an attribute to the second trial.

1. Select **Load Class Information** from the **File** menu

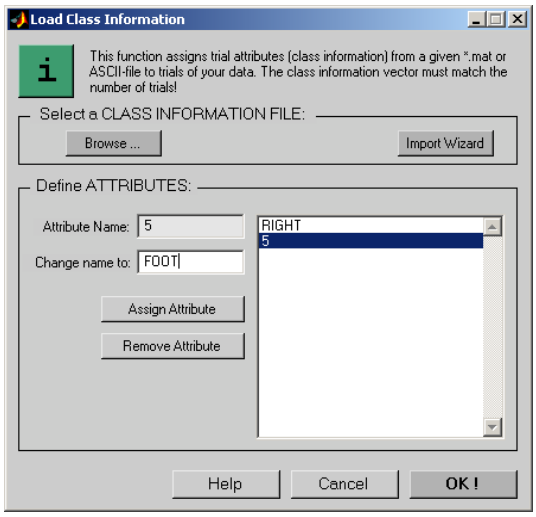
2. Click on the **Import Wizard**

3. Search for the class information file `class160.mat` in the same directory. The Import Wizard shows the variables stored in the file and gives a truncated preview of the class information.



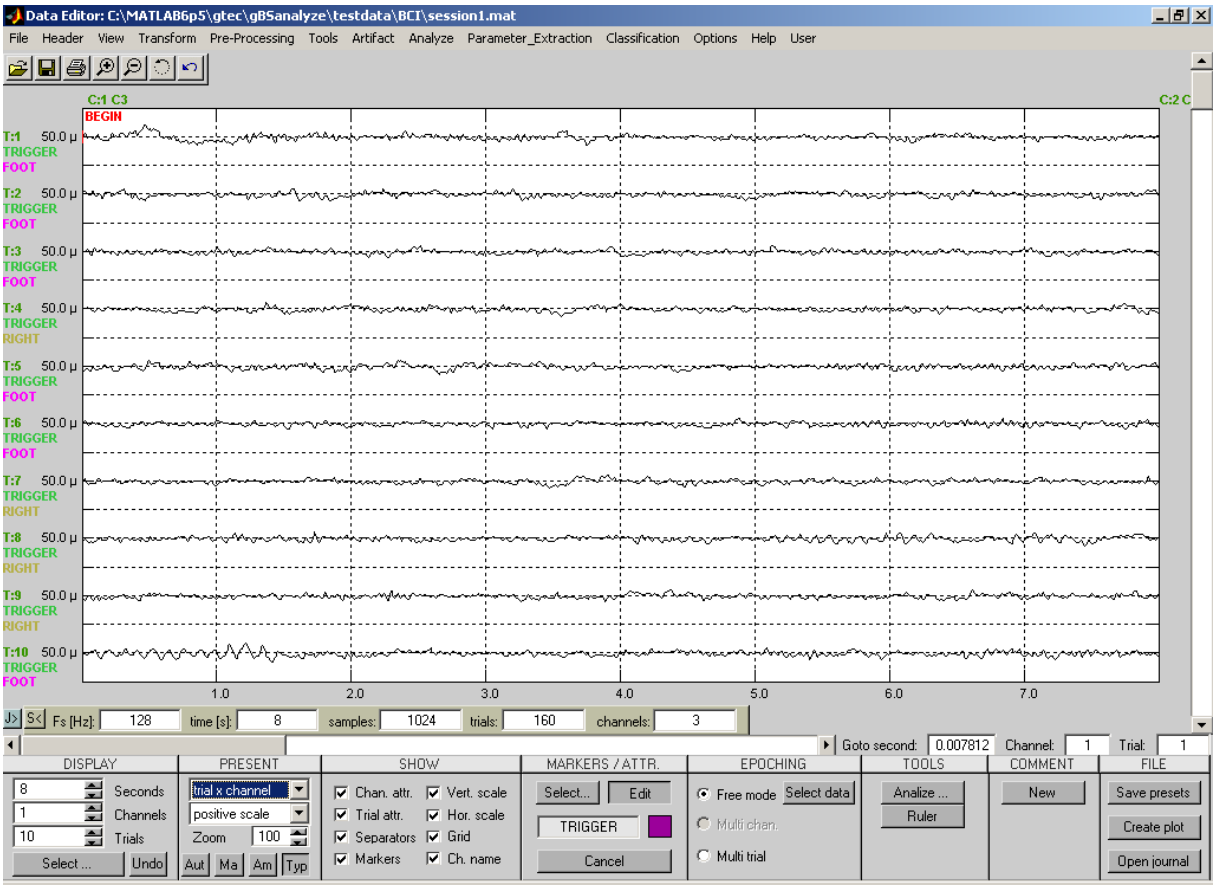
4. Click **Finish** to assign the attributes to the data trials. The window shows the attribute name 4 for the first row of the loaded class matrix and 5 for the second row.

5. Select the new-loaded attribute 4, enter the attribute name `RIGHT` and click **Assign Attribute**. Click on 5 and assign the name `FOOT`.



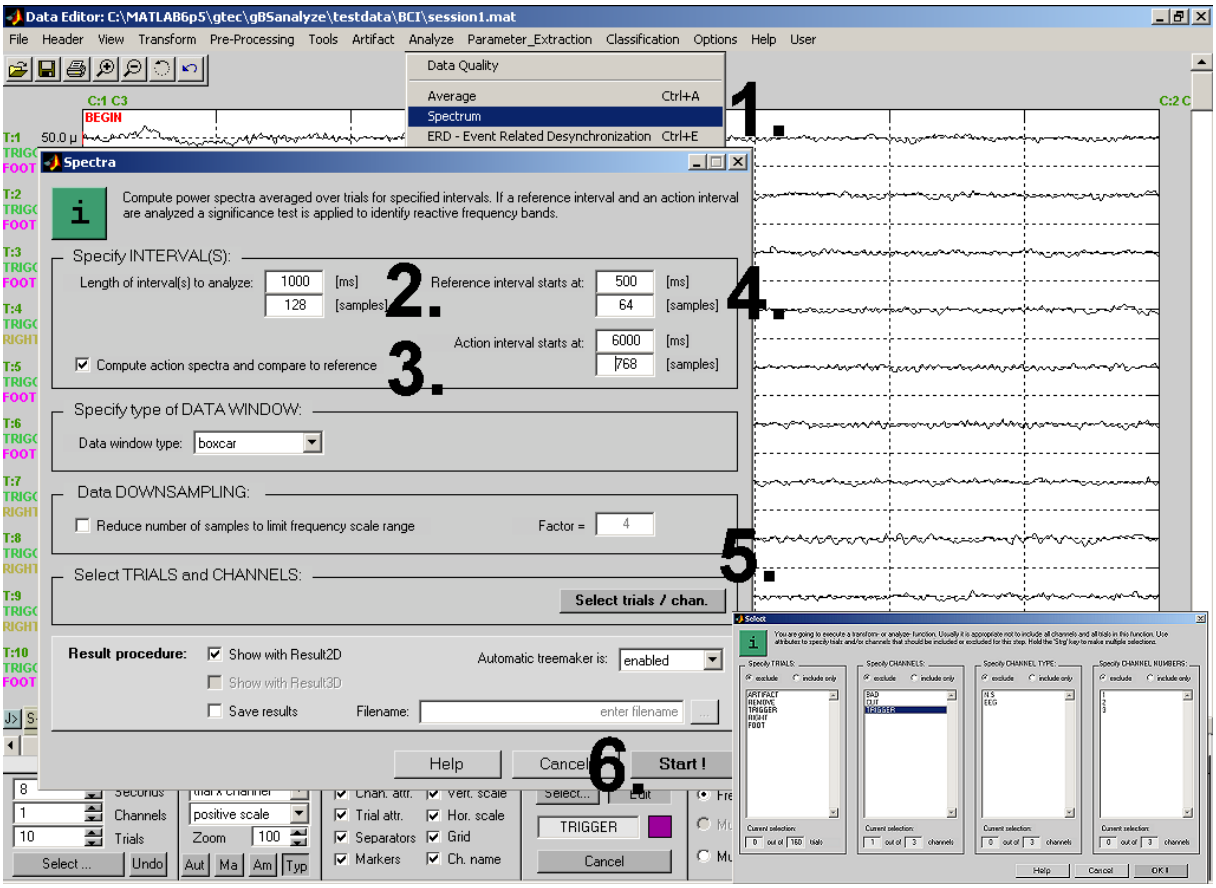
6. Close the window with **OK**. The attributes are assigned to your trials.

The assignment of attributes to the trials can be seen if you change to the `trial x channel` mode in the section **PRESENT** in the Data Editor. As can be seen the session started with 3 foot movement imageries. The first trial with a right motor imagery is trial number 4.

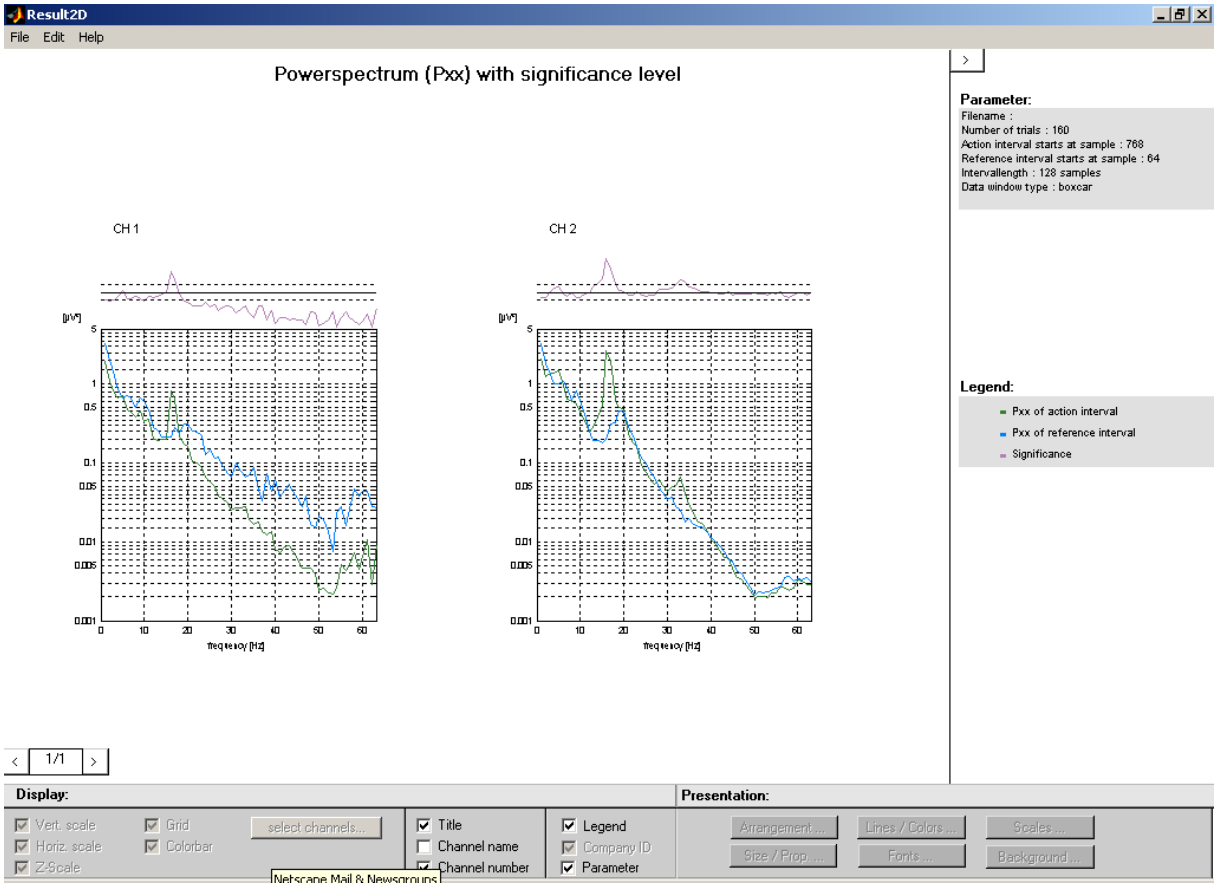

Data Editor: C:\MATLAB6p5\gtec\gBSanalyze\testdata\BCI\session1.mat
File Header View Transform Pre-Processing Tools Artifact Analyze Parameter_Extraction Classification Options Help User
C:1 C3
C:2 C
BEGIN
T:1 50.0 µ TRIGGER FOOT
T:2 50.0 µ TRIGGER FOOT
T:3 50.0 µ TRIGGER FOOT
T:4 50.0 µ TRIGGER RIGHT
T:5 50.0 µ TRIGGER FOOT
T:6 50.0 µ TRIGGER FOOT
T:7 50.0 µ TRIGGER RIGHT
T:8 50.0 µ TRIGGER RIGHT
T:9 50.0 µ TRIGGER RIGHT
T:10 50.0 µ TRIGGER FOOT
1.0 2.0 3.0 4.0 5.0 6.0 7.0
Fs [Hz]: 128 time [s]: 8 samples: 1024 trials: 160 channels: 3
Goto second: 0.007812 Channel: 1 Trial: 1
DISPLAY
8 Seconds
1 Channels
10 Trials
Select ... Undo
PRESENT
trial x channel
positive scale
Zoom 100
Aut Ma Am Typ
SHOW
Chan. attr. Vert. scale
Trial attr. Hor. scale
Separators Grid
Markers Ch. name
MARKERS / ATTR.
Select... Edit
TRIGGER
Cancel
EPOCHING
Free mode Select data
Multi chan.
Multi trial
TOOLS
Analize ...
Ruler
COMMENT
New
FILE
Save presets
Create plot
Open journal

6. Identify Reactive Frequency Components

1. Select **Spectrum** of the **Analyze** menu
2. Select `1000` ms as **Length of interval to analyze**
3. Check **Compute action spectra and compare to reference**
4. Set **Reference interval starts at** to `500` ms and **Action interval starts at** to `6000` ms
5. Click on **Select trials/chan.** and exclude the channels with attribute `TRIGGER` from the following calculation. Confirm the settings and close the window with **OK**.
6. Start the calculation with the **Start** button

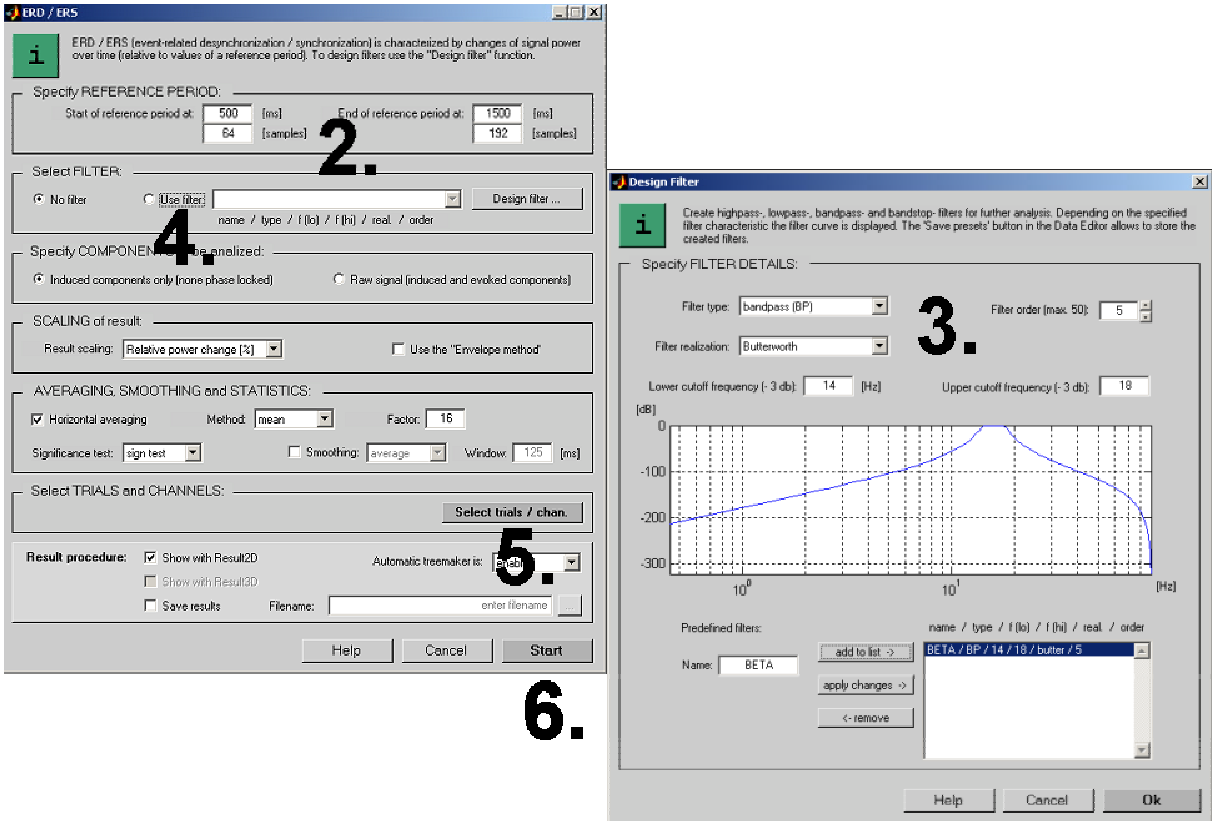


As can be seen the subject has a prominent rhythmic activity around 14 – 18 Hz over Cz which is different for action and reference period. However, differences can also be observed in the alpha band. The green line indicates the estimated power spectrum in the action interval and the blue line in the reference interval. The magenta lines at the top of the graphs display the significance level. The dotted lines represent the 95% significance levels for the power differences.



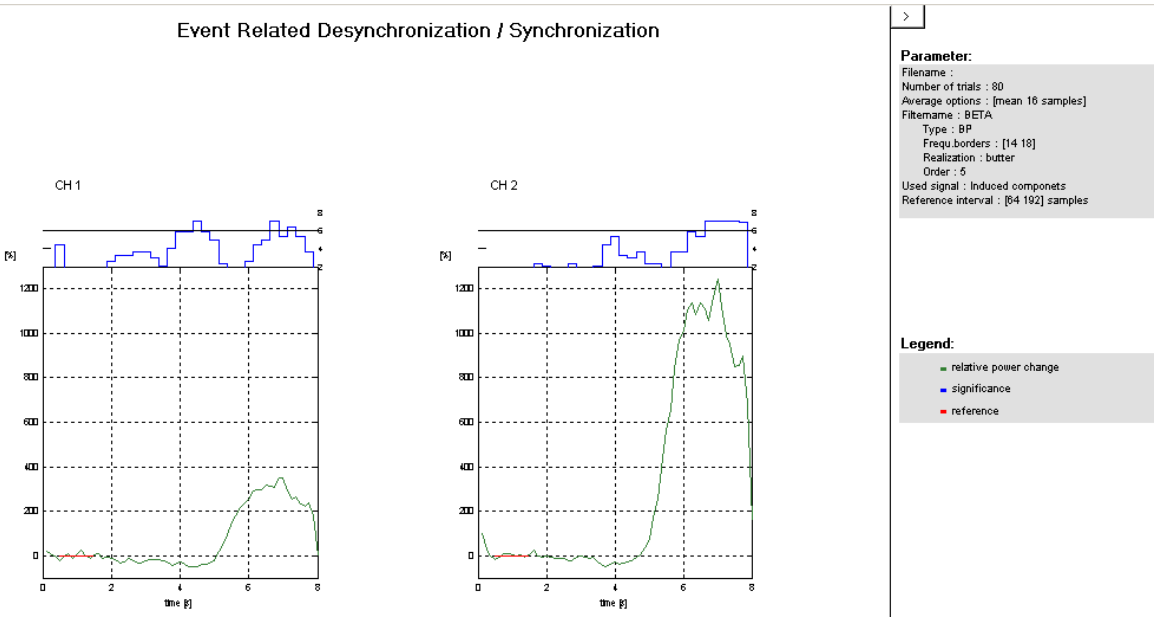
7. ERD Analysis

1. Open **ERD** under the **Analyze** menu entry
2. Select a reference period of `500` to `1500` ms



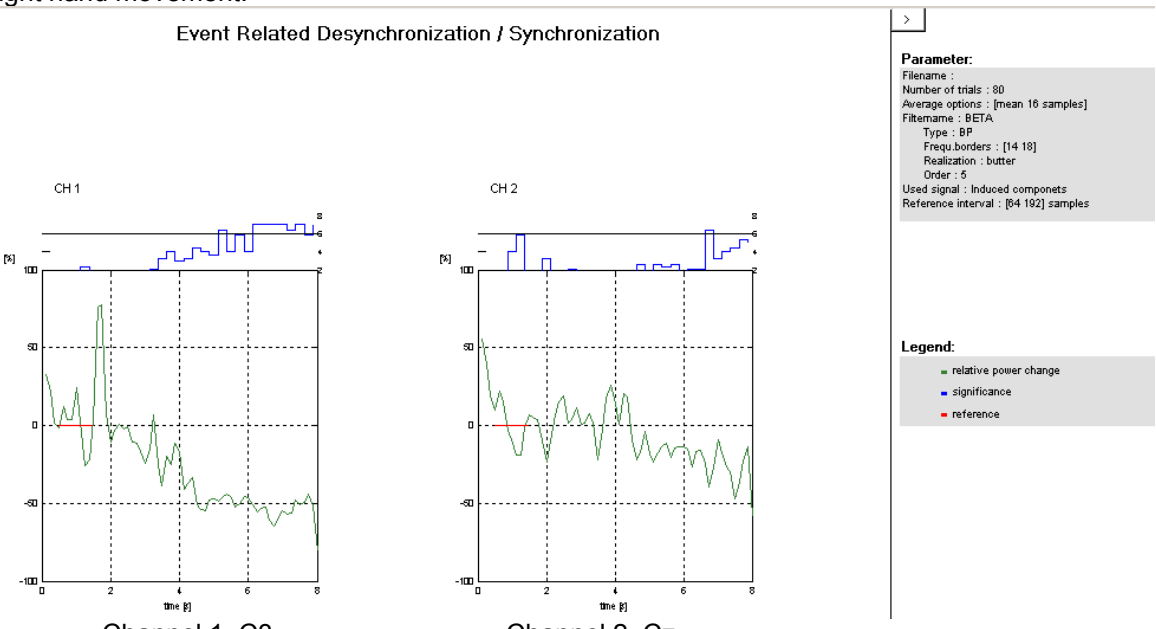
3. Click on **Design filter** and create a `Butterworth` filter with order `5` and a lower cutoff frequency of `14` Hz and an upper cutoff frequency of `18` Hz. Assign the **Name** `BETANEW`, `press` **add to list →** and press button **OK**
4. Check **Use filter** and select `BETANEW`
5. Click on **Select trials/chan.** and exclude the `TRIGGER` channel. Include only the `FOOT` trials. Close the window with **OK**
6. Press **OK** to perform the calculation
7. Repeat steps 5-6 and include only trials with the attribute `RIGHT`

The figure below shows ERD/ERS calculated between 14 and 18 Hz for trials with attribute `FOOT`.
It can be seen that a very pronounced ERS can be observed over channel Cz. The blue graphs on top of the figures display the significance level of the ERD/ERS changes. The solid line indicates the 95% significance level.



Channel 1, C3 Channel 2, Cz

The figure below shows ERD/ERS calculated between 14 and 18 Hz for trials with attribute `RIGHT`. It can be seen that the subject shows an ERD over the contralateral area (C3) during the imagination of the right hand movement.



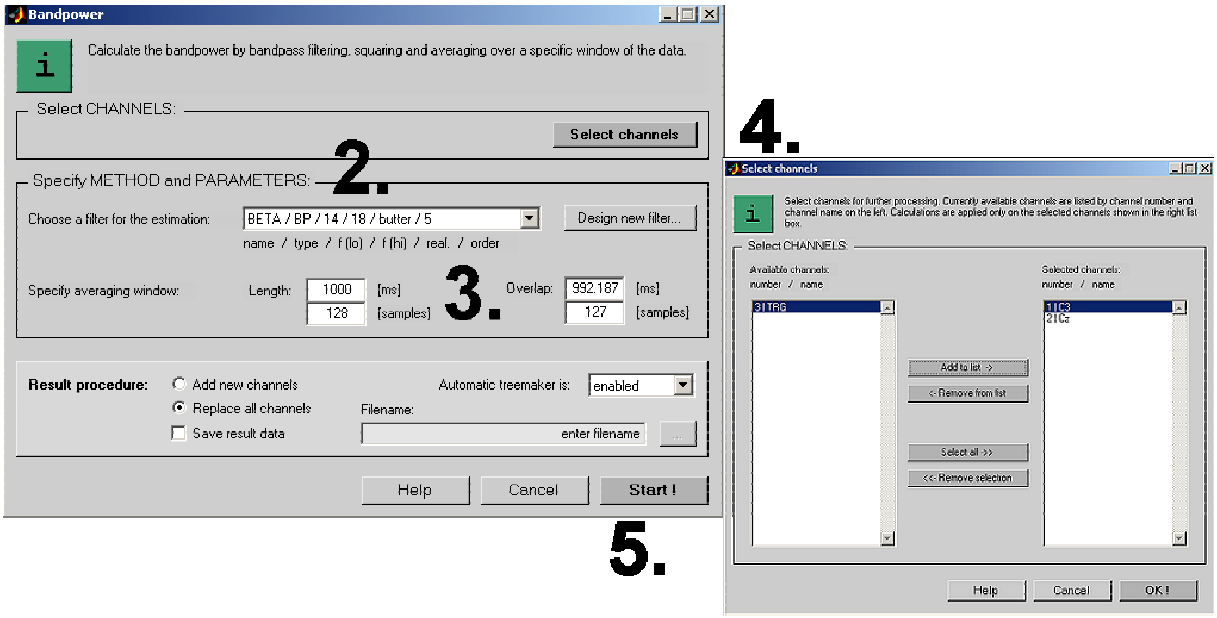
Channel 1, C3 Channel 2, Cz

8. Feature Extraction

This function of the **Parameter Extraction** menu computes the band power within a certain frequency range of the selected channels. The band power is estimated by digitally band pass filtering the data, squaring and averaging over consecutive samples according to the window length.

Perform the following steps to calculate the band power:

1. Click on **Bandpower** under the **Parameter Extraction** menu to open the following window:



2. Select the created `BETANEW filter` with the bandwidth of 14 to `18` Hz

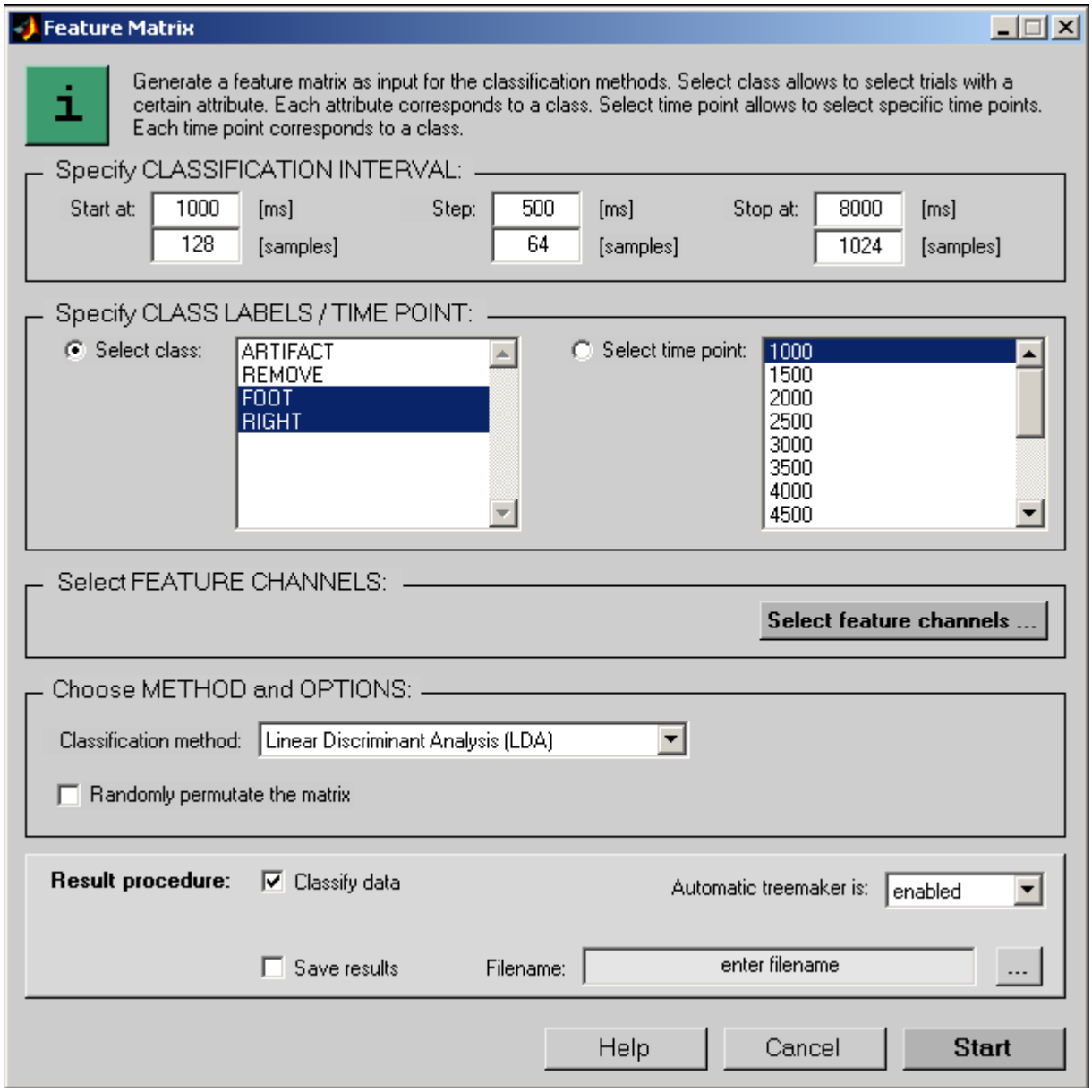
3. Specify the length of the estimation interval as `128` samples with overlap of `127` samples. Attention: No other overlap is allowed in the DEMO mode

4. Click on **Select channels** and add the EEG channels C3 and Cz to the list. Confirm the settings with the **OK** button.

5. Press **Start** to calculate the parameters

9. Data Set Classification

1. Select **Feature Matrix** from menu **Classification**
2. Set the classification interval to **Start at** `1000` ms, **End at** `8000` ms and **Step** to `500` ms
3. Select as **Class1** `RIGHT` and **Class2** `FOOT`
4. Click on **Select feature channels …** and select channels 1 and 2 for classification
5. Select `Linear Discriminant Analysis (LDA)` from the **Classification method** pull-down menu
6. Press **Start**

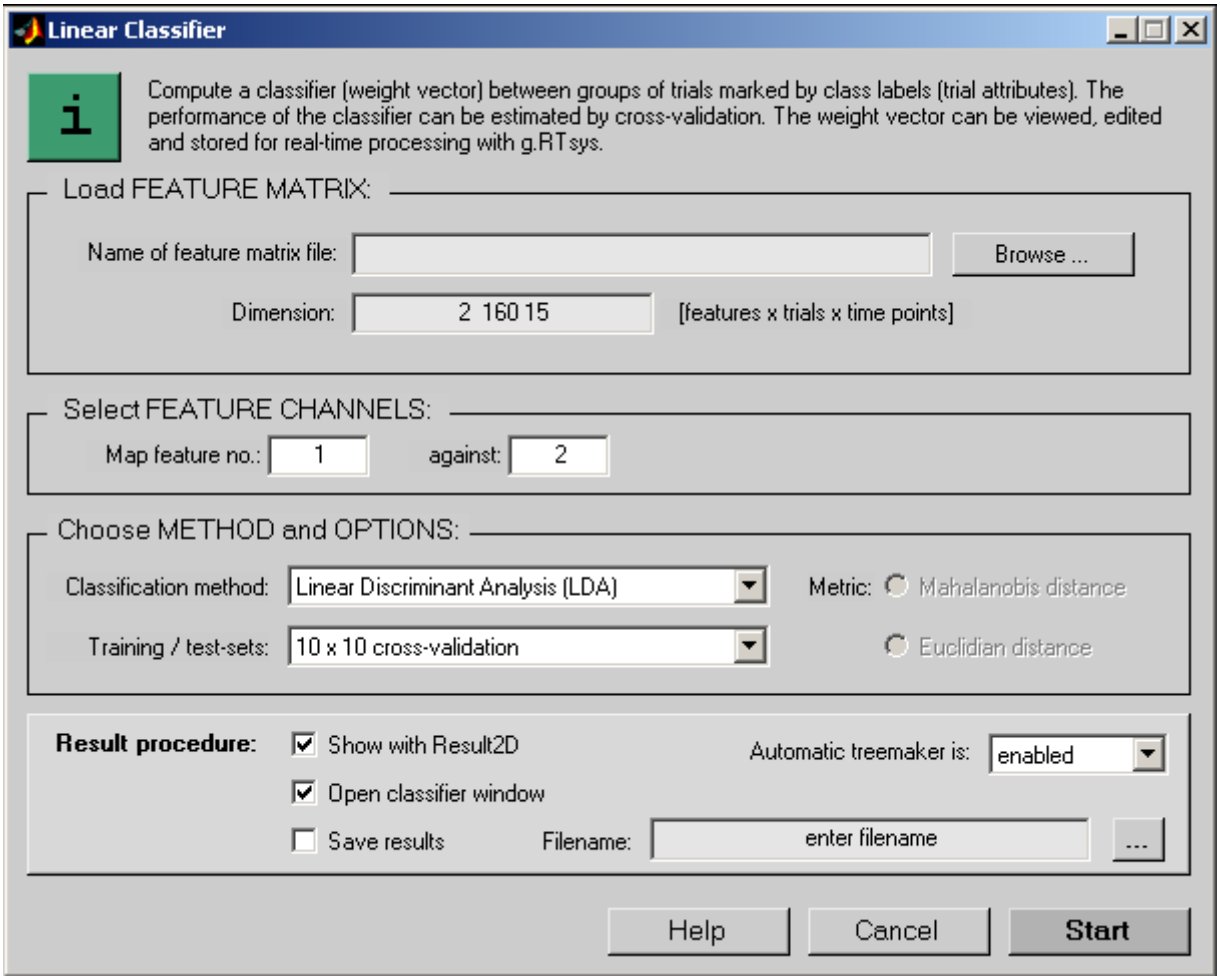


The **Linear Classifier** window opens with the created feature matrix. The feature matrix contains 2 features (channels 1 and 2), with 160 examples and 15 time points (1000, 1500, … 8000 ms).

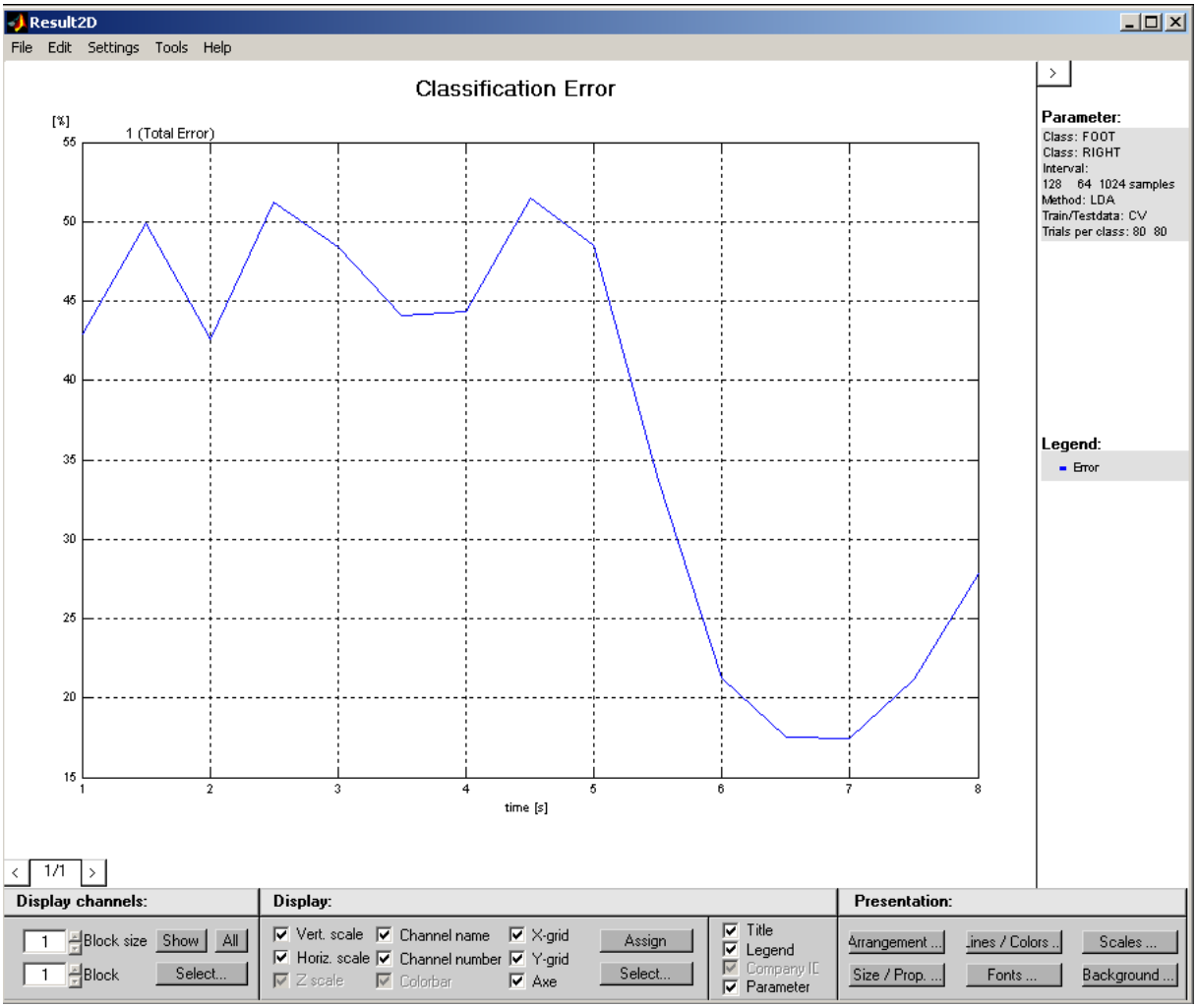
1. Select under **Classification method** `Linear Discriminant Analysis (LDA)` and `10 x 10 cross-validation` to randomly mix the training and testing data.

2. Check **Show with Result2D** and **Open classifier window**

3. Press **Start**



The classification results for RIGHT and FOOT movement imagery are given in the graph below. At the beginning of the trial the error is around 50%. After second 5 (arrow is show on the screen at second 3) the error drops down. The best error of about 16 % can be found at second 7 of the trial. This means that the data set can be classified with an accuracy of about 84 %.



To further improve the classification result calculate also the bandpower in the alpha range of the EEG. Identify the optimal frequency range from the ERD analysis results.

Reference:

[Guger 2001] C. Guger, A. Schlögl, C. Neuper, D. Walterspacher, T. Strein, and G. Pfurtscheller, "Rapid Prototyping of an EEG-based brain-computer interface (BCI)," IEEE Trans. Rehab. Engng., vol. 9, 2001.